Making the Dream Catalyst a Reality

Without platinum, they don't work, but with it, they're too expensive: the noble metal is the catalyst and core component of fuel cells. Researchers from Berlin and Jülich are currently working on a variant that is just as efficient but requires less platinum. Electron microscopes with ultrahigh resolution are aiding their efforts.

Individual atoms light up as white spots on a grey background on the monitor in front of Jülich researcher Dr. Marc Heggen. They are platinum and nickel atoms, arranged in triangles that form an octahedron measuring almost 10 nanometres. Seen from above, it looks like the Great Pyramid of Giza.

Marc Heggen is sitting in front of one of the world's best ultrahigh-resolution electron microscopes at Jülich's Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons. On his monitor, he is looking at one of the most powerful catalysts ever developed for fuel cells.

For years, scientists have been competing with each other to produce the most effective catalyst for fuel cells. The reasons are simple. Fuel cells produce electrical energy from the energy carrier hydrogen when it reacts with oxygen. In this process, the only waste produced is water. In electric cars, for example, fuel cells could replace the battery. The advantages: fuel cells are lighter than batteries. They would also allow electric cars to be fuelled with hydrogen, which is easier and faster than recharging a battery.

However, the crux is that fuel cells require the expensive platinum as a catalyst. "It is the platinum in the electrodes that triggers the reaction between hydrogen and oxygen," says Heggen. Without platinum, the fuel cell wouldn't work, but when it's used, the fuel cell is too expensive to be competitive.

DECISIVE GEOMETRY

For some time now, scientists have therefore been working on developing catalysts that deliver the same perfor-

More expensive than gold: the high price of platinum prevents fuel cells from being used on a commercial scale.

mance with less platinum. One option is to mix platinum with baser metals such as nickel. Since catalysis takes place at the surface where the atoms dock on to the material, nanoparticles that are as small as possible are particularly useful, because they have a larger surface area at identical mass. Although they reduce the amount of platinum required, the small particles tend to clump together when used in fuel cells, which decreases the lifetime of the catalysts.

In 2007, the chemical physicist Stamenkovic had another exciting idea. He showed that an alloy of platinum and nickel with the crystallographic surface of an octahedron is theoretically 90 times more effective than conventional catalysts. Heggen explains: "Platinum-nickel octahedra measuring a few nanometres that remain stable during the reaction are the ultimate dream catalyst for fuel cells." The nanogeometry of the surface is decisive for increasing the performance of the catalyst.

Ever since the Serbian researcher described this ideal catalyst, scientists all over the world have been attempting to actually produce it. Heggen and his project partners at TU Berlin are also contenders in this race. The chemists in Berlin synthesize platinum-nickel nanoparticles and Heggen examines them with electron microscopes. He then provides "microfeedback", which helps his colleagues in Berlin to refine the nanoparticle catalysts.

A look at minute details: with the help of an electron microscope, Marc Heggen examines the atomic structure of potential dream catalysts for fuel cells.

A few months ago, the team achieved a breakthrough: "We produced a catalyst that is ten times more efficient than comparable platinum nanoparticles, and therefore one of the most powerful catalysts ever developed," says Heggen. However, a number of questions have yet to be answered: Do the particles have the correct octahedral shape? How exactly are the atoms arranged? And what happens to them when the catalyst is in operation?

SURPRISING PATTERN DISCOVERED

Answering such questions is an important step towards further optimizing the catalyst. Heggen therefore examines the nanoparticles at the Ernst Ruska-Centre using microscopes with an internationally unrivalled accuracy. By means of scanning electron microscopy and electron energy loss spectroscopy, he has taken extremely accurate "snapshots". They show each and every atom in the octahedron.

"We discovered a surprising pattern," says Heggen. "The atoms aren't as evenly distributed as we had assumed. Plenty of platinum accumulated at the edges of the octahedron, while nickel was distributed on the faces." This impairs both the activity and lifetime of the catalyst. "During operation, the nickel atoms dissolve, causing the initial formation of concave surfaces, until eventually, a platinum frame is all that's left. The faces of the octahedron are valuable for the reaction and when they disappear, the activity of the catalyst declines," says Heggen. "We now know how we can improve the catalyst further, and we already have a few ideas to prevent nickel from accumulating on the faces of the octahedron."

The physicist will soon receive new, optimized nanoparticles, which he will examine with an electron microscope. It is quite possible that one of them will turn out to be the dream catalyst that will help to power electric cars in the future. ::

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